# The effects of real exchange rate volatility on productivity growth

Diallo, Ibrahima Amadou
Centre d'Études et de Recherches sur le Développement International, CERDI

24. January 2012

# The Effects of Real Exchange Rate Volatility on Productivity Growth

Diallo Ibrahima Amadou[1]

January, 2012

## Abstract

This paper employs panel data instrumental variable regression and threshold effect estimation methods to study the link between real effective exchange rate volatility and total factor productivity growth on a sample of 74 countries on six non overlapping sub-periods spanning in total from 1975 to 2004. The results illustrate that real effective exchange rate volatility affects negatively total factor productivity growth. But this effect is not very high. This outcome is corroborated by estimations using an alternative measurement of real effective exchange rate volatility and on a subsample of developed countries. But for developing countries the negative effect of real effective exchange rate volatility is very large. We also found that real effective exchange rate volatility acts on total factor productivity according to the level of financial development. For very low and very high levels of financial development, real exchange rate volatility has no effect on productivity growth but for moderately financially developed countries, real exchange rate volatility reacts negatively on productivity.

*Keywords:* *real effective exchange rate; volatility; total factor productivity growth; panel data instrumental variable regression; threshold effect estimation; stochastic frontier analysis*

*JEL Classification:* *F3, F41, O47*

[1] Clermont University, University of Auvergne, Centre d'Études et de Recherches sur le Développement International, CERDI-CNRS, 65, bd François Mitterrand, 63000 Clermont-Ferrand, France. Contact : zavren@gmail.com

## **Introduction**

Traditionally, economists think that there is no link between business cycle and economic growth but since the seminal work of *Ramey and Ramey (1995)* there has been a growing interest in the study of the effects of volatility on growth. Researchers consider that volatility can have three different impacts on output growth: a positive effect, a negative effect and no effect. First, the defenders of a positive outcome argue that more volatility leads to higher precautionary saving and hence to higher economic growth. Volatility can also act positively on growth by the fact that it is associated with recessions which lead to the destruction of less productive firms and to higher Research and Development (R&D) expenditures *(Schumpeter (1939)* and, *Aghion and Saint-Paul (1998))*. Second, the negative effect of volatility on growth dates back to *Keynes (1936)* who states that investors take into account fluctuations of economic activity when calculating return on investment. Furthermore, high volatility can lead to lower investment if investment is irreversible *(Bernanke (1983)*, and *Aizenman and Marion (1993*)). Some researchers argue that, if there exist a strong relationship between recessions and the worsening of fiscal constraints, then high volatility could lead to lower growth. In fact, recessions could lead to less human capital accumulation and hence a reduction in growth. Volatility can also reduce growth by increasing the observed riskiness of investment projects which diminishes investment. Other causes of a negative impact of volatility on growth are macroeconomic instability, weak institutions and political insecurity. Third, those who believe in the no effect hypothesis argue that only real factors like technology and labor skills can affect output growth. In the empirical literature, *Ramey and Ramey (1995)* and *Norrbin and Yigit (2005)* find a negative link between volatility and growth. *Hnatkovska and Loayza (2003)* find that this negative relationship is largely due to big recessions and is aggravated in countries that are weak institutionally, poor, incapable to take countercyclical fiscal policies and financially underdeveloped. The results of *Imbs (2006)* show that volatility and growth are correlated positively across sectors and negatively across countries. *Kormendi and MeGuire (1985),* and *Grier and Tullock (1989)* find that countries with higher volatility experience higher growth rate. *Rafferty (2005)* shows that expected volatility raises growth while unexpected volatility diminishes growth. His results also illustrate that the joined impact of expected and unexpected volatility reduces long-term growth most of the time and for many countries.

In the same line of the study of the relationship between business cycle and growth, researchers have recently considered the link between exchange rate volatility and growth in general and between exchange rate volatility and productivity in particular. For the exchange rate volatility-growth nexus, studies show that it can be both positive and negative. In the first place, exchange rate volatility acts positively on growth by allowing the use of very flexible monetary policy instruments in case of asymmetric shocks *(Friedman (1953)).* In the second place, a negative relationship can occur due to the inefficient foreign exchange markets in developing countries and to the uncertainty introduced by the volatility of the macroeconomic environment. Exchange volatility can have an ambiguous effect on growth by changing the relative costs of production *(Klein et al. (2003)).* Exchange rate instability can also have a vague impact on investment, inventories and employment by decreasing the credit available from the banking system. Exchange volatility can have a negative effect on growth by raising interest rates and increasing inflation instability. Exchange rate uncertainty can harm trade and consequently growth by increasing transaction risk *(Grier and Smallwood (2007))*. Some authors argue that, in developing countries, real exchange rate instability could have a more bad impact on growth because of low financial development and the presence of dollarization. Real exchange rate variations alter market signals and lead to an inefficient allocation of investment *(Guillaumont (1999))*. Real exchange rate variations can also acts negatively on investment by the uncertain environment it generates. In fact, an unstable economic situation created by exchange rate volatility can push economic agents to lose confidence in government policies which could damage the expected return on investment and thus reduce growth. For the empirical literature, *Drautzburg (2007)* find a significant negative impact of real exchange rate instability on growth for low-income countries while the effect for high-income countries is ambiguous. *Schnabl (2007)* also discover a negative link between exchange rate volatility and growth for a sample of 41 countries at the European Monetary Union periphery from 1994 to 2005.

In the literature, there are two papers that study the relationship between exchange rate volatility and productivity growth: *Aghion et al. (2006)* and *Benhima (2010)*. *Aghion et al. (2006)* use a panel of 83 countries from 1960 to 2000. They find that real exchange rate volatility can have a non-negligible effect on productivity growth, and the impact is function of the level of the financial development of the countries. Exchange rate volatility acts negatively on productivity growth in countries with low levels of financial development while it has no effect on countries with high levels of financial development. *Benhima (2010)* argues that the effect of exchange rate flexibility on productivity can also depend on liability dollarization. In a panel of 76 countries going from 1995 to 2004, he discovers that the negative impact of exchange rate flexibility on productivity is more pronounced in countries with high degree of dollarization.

Like these two previous studies, this paper examines, empirically, the relationship between real exchange rate volatility and productivity growth. But it differentiates itself in the following way. Firstly, in the previous literature, productivity growth is measured as the ratio of real output per worker. Thus the variable used for productivity growth is a measurement of partial productivity. To solve this problem, we introduce a new measurement of total factor productivity growth derived from the stochastic production frontier literature *(Kumbhakar and Lovell (2000))*. Secondly, to take account the potential nonlinear effects of real exchange rate volatility on productivity growth, the previous works use an interaction of real exchange rate volatility and financial development. There is no problem with this econometric method but it only captures the nonlinearity in the variables. To solve this, we utilize the *Hansen (1999)* method of estimating thresholds effects in non-dynamic panel data. This method allows us to take account the potential existence of nonlinearity. Thirdly, we introduce two measurements of real exchange rate volatility that have not been used before. The results show, first, that real exchange rate volatility affects negatively productivity growth. Second, the results illustrate that the effect of real exchange rate volatility on productivity depends on the level of financial development. For very low levels of financial development, real exchange rate volatility has no effect on productivity growth. For moderately financially developed countries, real exchange rate volatility reacts negatively on productivity and for highly financially developed countries, real exchange rate volatility has no effect on productivity.

The remaining of the paper is organized as follow. Section 1 presents the econometric methods used. Section 2 deals with the data and variables. Section 3 gives the results and the last part concludes.

## 1. Econometric models and estimations methods

In this section, we give a brief review of the econometric methods used to estimate the relationship between real exchange rate volatility and productivity growth.

### 1.1. The panel data instrumental variable estimation method

We use the panel data instrumental variable method to estimate a model of the form:

$$TFPG_{it} = \alpha REERVOL_{it} + X_{it}\beta + \mu_i + \varepsilon_{it} \tag{1}$$

Where $TFPG_{it}$ is the total factor productivity growth; $REERVOL_{it}$ the logarithm of real effective exchange rate volatility; $X_{it}$ indicates the control variables utilized in the study; $\mu_i$ are the individual specific effects; $\varepsilon_{it}$ is the idiosyncratic error term; $i$ specifies countries and $t$ the time. The control variables used are: financial development, openness, human capital, government consumption, inflation, tendency of terms of trade and a crises variable. See Table 1 for the definition and source of the control variables. Table 2 shows the summary statistics on the variables.

We use panel data instrumental variable to estimate the model in (1) because we suspect real exchange rate volatility to be endogenous. We think this because of the *Balassa-Samuelson* effect. This effect states that productivity affects real exchange rate. The effect supposes that productivity increases rapidly in the tradable sector than in the non-tradable sector. This causes an increase of the wages in the tradable sector. This in turn put an upward pressure on wages, particularly on the wages in the non-tradable sector. Because the prices of tradable goods are internationally determined, high wages in the non-tradable sector cause high relative price of non-tradable goods. Hence an appreciation of the real exchange rate. This theorem makes that real exchange rate volatility is endogenous. Consequently we must find instruments in order to consistently estimate the effect of real exchange rate volatility on productivity growth. Econometrics theory says that a good instrument must be uncorrelated with the error $\varepsilon_{it}$ and correlated with the real exchange rate volatility. Thus variations in the instruments are related with variations in real exchange rate volatility but do not cause variations in productivity growth, excluding indirectly through real exchange rate volatility. From the literature on the determinants of real exchange rate volatility, *Caporale et al. 2009* identifies the following variables: lagged real exchange rate volatility, volatility of terms of trade, volatility of real GDP, volatility of public expenditure, volatility of money supply, openness, FDI and portfolio investments, total liabilities and assets relative to GDP, Net Foreign Assets, and exchange rate regime. Except for lagged real exchange rate volatility, these variables cited previously are also, one way or the other, identified in the literature as determinants of productivity or real GDP per capita growth. Hence these variables do not strictly satisfy the properties of good instruments for our present study. That is why we use only lagged real exchange rate volatility as instrument.

### 1.2. The threshold effect estimation method

We utilize the *Hansen (1999)* method of finding thresholds effects in non-dynamic panel data to estimate an equation having the following form:

$$TFPG_{it} = \alpha_1 REERVOL_{it} I(FD_{it} \leq \gamma) + \alpha_2 REERVOL_{it} I(FD_{it} > \gamma) + X_{it}\beta + \mu_i + \varepsilon_{it} \quad (2)$$

Where $I(\cdot)$ is the indicator function; $FD_{it}$ is the financial development variable (ratio of domestic credit to private sector to GDP); $\gamma$ is the threshold level; $\alpha_1$ and $\alpha_2$ are the marginal effects of real exchange rate volatility which can be different according to the threshold level; all other variables are defined the same way as in equation (1). We test the null hypothesis of linearity of real exchange rate volatility $\left(H_0 : \alpha_1 = \alpha_2\right)$ against the alternative hypothesis $\left(H_a : \alpha_1 \neq \alpha_2\right)$. The *Hansen (1999)* method consists of estimating equation (2) for different values of the threshold level $\gamma$. We retain the value of $\gamma$ that minimize the sum of squared residuals:

$$\hat{\gamma} = \arg\min_{\gamma} S_1(\gamma) \qquad (3)$$

With $S_1(\gamma) = \hat{\varepsilon}(\gamma)' \hat{\varepsilon}(\gamma)$ is the sum of squared residuals under $H_a$; $\hat{\varepsilon}(\gamma)$ are the estimated residuals. Next we test for the statistical significance of the threshold level. To do this, *Hansen (1999)* proposes a likelihood ratio test that allows comparing the models with and without break:

$$F_1 = \frac{S_0 - S_1(\hat{\gamma})}{\hat{\sigma}^2} \qquad (4)$$

Where $S_0$ is the sum of squared residuals under $H_0$; $S_1(\hat{\gamma})$ is the sum of squared residuals under $H_a$ at the estimated threshold level $\hat{\gamma}$; $\hat{\sigma}^2$ is the variance of the residuals in the model without break ($\hat{\sigma}^2 = \frac{1}{n(T-1)} S_1(\hat{\gamma})$). *Hansen (1999)* argues that the distribution of the statistic $F_1$ is non-standard and strictly dominates that of the chi-squared distribution with $k$ degrees of freedom. Hence critical values of this statistic cannot be obtained. To solve this, he suggests a bootstrap procedure to recover the p-value of $F_1$. *Hansen (1999)* also proposes to build a confidence interval for the estimated threshold level. He gives the following likelihood ratio:

$$LR_1(\gamma) = \frac{S_1(\gamma) - S_1(\hat{\gamma})}{\hat{\sigma}^2} \qquad (5)$$

It is important to note that at $\gamma = \hat{\gamma}$ we have $LR_1(\hat{\gamma}) = 0$ and as he pointed out that $LR_1(\gamma)$ is different from $F_1$. *Hansen (1999)* demonstrates that the statistic $LR_1(\gamma)$ tends toward the random variable $\xi$ having the following distribution $P(\xi \le x) = \left(1 - \exp\left(-\frac{x}{2}\right)\right)^2$. By inverting this distribution, we find the following function $c(\alpha) = -2\log\left(1 - \sqrt{1-\alpha}\right)$. This function allows calculating the confidence interval for $\hat{\gamma}$. For a critical value of $\alpha\%$, the confidence interval corresponds to the values for which we have $LR_1(\gamma) \le c(\alpha)$. He shows that this confidence interval is easy to find graphically by first plotting $LR_1(\gamma)$ against $\gamma$ and second drawing a horizontal line at $c(\alpha)$. Hence the confidence interval corresponds to the values of $LR_1(\gamma)$ that are below the horizontal line and $\hat{\gamma}$ is where the curve of $LR_1(\gamma)$ touches the x-axis.

In this study we use a triple threshold model. This means that we can rewrite equation (2) as:

$$\begin{aligned} TFPG_{it} &= \alpha_1 REERVOL_{it} I(FD_{it} \le \gamma_1) + \alpha_2 REERVOL_{it} I(\gamma_1 < FD_{it} \le \gamma_2) \\ &+ \alpha_3 REERVOL_{it} I(\gamma_2 < FD_{it} \le \gamma_3) + \alpha_4 REERVOL_{it} I(\gamma_3 < FD_{it}) \qquad (6) \\ &+ X_{it}\beta + \mu_i + \varepsilon_{it} \end{aligned}$$

Where the thresholds are ordered, hence $\gamma_1 < \gamma_2 < \gamma_3$. The inference for equation (6) follows the same reasoning as before but by taking into account the presence of threshold at each step. For more details on this, please see *Hansen (1999)*. It is important to note that *Hansen (1999)* discusses in detail the double threshold model but he argued that his reasoning could be easily extended to more than two thresholds models. His program, which we use in this study, allows for the case of triple threshold.

## 2. Data and variables of interest

In this section, we present the data used in the study and show how the variables of interest are calculated.

### 2.1. Data used in the study

The sample of study contains 74 countries: (24) developed and (50) developing countries over the period 1975-2004. The choice of the sample is based on the availability of data. To get rid of cyclical fluctuations and focus on middle and long term relations, the averages over five years were calculated. Therefore, the temporal depth was reduced to six non overlapping sub-periods: 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, and 2000-2004. This method of averaging over sub-periods is frequently used in the empirical growth literature. The data essentially come from the World Bank (World Development Indicators, 2006), *Barro and Lee (2010)*, International Financial Statistics (IFS), April 2006, Centre D'études Et De Recherches Sur Le Développement International (CERDI) 2006, Caprio *and Klingebiel (2003)*, and *Kaminski and Reinhart (1999)*. Table 3 gives the list of all countries used in the study.

The real effective exchange rate (REER) is calculated according to the following formula:

$$REER_{i/j} = \prod_{j=1}^{10} \left( NBER_{j/i} \frac{CPI_i}{CPI_j} \right)^{\omega j} \qquad (7)$$

Where:

$NBER_{j/i}$: is the nominal bilateral exchange rate of trade partner $j$ relative to country $i$

$CPI_i$: represents the consumer price index of country $i$ (IFS line 64). When the country $CPI$ is missing, the growth rate of the GDP deflator is used to feel the gap;

$CPI_j$: corresponds to the consumer price index of trade partner $j$ (IFS line 64). When the country $CPI$ is missing, the growth rate of the GDP deflator is used to feel the gap;

$\omega_j$: stands for trade partner $j$ weight (mean 1999-2003, PCTAS-SITC-Rev.3). Only the first ten partners are taking (CERDI method). These first ten partners constitute approximately 70% of the trade weights. The weights used to generate the REER are $\dfrac{\dfrac{\text{Exports}_j + \text{Imports}_j}{2}}{\sum_{j=1}^{10} \dfrac{\text{Exports}_j + \text{Imports}_j}{2}}$ excluding oil countries. Weights are computed at the end of the period of study in order to focus on the competitiveness of the most recent years.

An increase of the REER indicates an appreciation and, hence a potential loss of competitiveness.

## 2.2. Measurement of variables of interest

In this subsection we illustrate how the total factor productivity growth and real exchange rate volatility are measured.

### 2.2.1. The calculation of total factor productivity growth

We use the primal approach of decomposition of productivity developed by *Kumbhakar and Lovell (2000)*. The stochastic production function can be writing as follows:

$$y_{it} = f\left(x_{it}, t; \beta\right) \cdot \exp\left(-u_{it}\right) \cdot \exp\left(v_{it}\right) \qquad (8)$$

Where $y_{it}$ is the output; $f\left(x_{it}, t; \beta\right)$ is the deterministic core of the stochastic production frontier; $\beta$ are the parameters to be estimated; $x_{it}$ represents inputs (the inputs here are capital $K_{it}$ and labour $L_{it}$); $\exp\left(-u_{it}\right)$ is the technical efficiency; $v_{it}$ is the stochastic error term; $t$ indicates time and $i$ indexes the countries. If technical inefficiency $u_{it} \geq 0$, then technical efficiency, $\exp\left(-u_{it}\right)$, lies in the range $(0,1]$. By dropping the error term from equation (8), the deterministic production function can be writing as:

$$y_{it} = f\left(x_{it}, t; \beta\right) \cdot \exp\left(-u_{it}\right) \qquad (9)$$

If we first take the natural logarithm of (9) and then differentiate with respect to time $t$, we obtain:

$$\frac{\partial \ln y_{it}}{\partial t} = \frac{\partial \ln f(x_{it}, t; \beta)}{\partial t} + \sum_{j=1}^{2} \frac{\partial \ln f(x_{it}, t; \beta)}{\partial \ln x_{itj}} \frac{\partial \ln x_{itj}}{\partial t} + \frac{\partial \ln \exp\left(-u_{it}\right)}{\partial t} \qquad (10)$$

With $\dot{y}_{it} = \frac{\partial \ln y_{it}}{\partial t}$ is the growth rate of output; $T\Delta_{it} = \frac{\partial \ln f(x_{it}, t; \beta)}{\partial t}$ is the rate of technical change; $\alpha_{itj} = \frac{\partial \ln f(x_{it}, t; \beta)}{\partial \ln x_{itj}}$ is the output elasticity of factor $j$; $\dot{x}_{itj} = \frac{\partial \ln x_{itj}}{\partial t}$ is the growth rate of input $j$ and $TE\Delta_{it} = \frac{\partial \ln \exp\left(-u_{it}\right)}{\partial t} = -\frac{\partial u_{it}}{\partial t}$ is the rate of change in technical efficiency. With these notations, we can rewrite equation (10) as:

$$\dot{y}_{it} = T\Delta_{it} + \sum_{j=1}^{2} \alpha_{itj} \dot{x}_{itj} + TE\Delta_{it} \tag{11}$$

The growth rate of total factor productivity ($TFPG_{it} = \dot{TFP}_{it}$) is defined according to the following Divisia index:

$$TFPG_{it} = \dot{TFP}_{it} = \dot{y}_{it} - \dot{x}_{it} = \dot{y}_{it} - \sum_{j=1}^{2} s_{itj} \dot{x}_{itj} \tag{12}$$

Where a dot over a variable designates the growth rate of that variable; $s_{itj} = \frac{w_{itj} x_{itj}}{\sum_{j=1}^{2} w_{itj} x_{itj}}$ is the input share of factor $j$ to total expenditure in country $i$ at time $t$; $w_{itj}$ is the price of factor $j$ in country $i$ at time $t$. Inserting equation (11) into equation (12) and after some algebra, we get:

$$TFPG_{it} = T\Delta_{it} + \left(RTS_{it} - 1\right) \sum_{j=1}^{2} \lambda_{itj} \dot{x}_{itj} + TE\Delta_{it} + \sum_{j=1}^{2} \left(\lambda_{itj} - s_{itj}\right) \dot{x}_{itj} \tag{13}$$

Where $RTS_{it} = \sum_{j=1}^{2} \alpha_{itj}$ is the return to scale and $\lambda_{itj} = \frac{\alpha_{itj}}{RTS_{it}}$ represents the optimal marginal output share of factor $j$. Equation (13) illustrates that the total factor productivity growth is a sum of four terms: technical change $T\Delta_{it}$, scale effect $\left(RTS_{it} - 1\right)\sum_{j=1}^{2} \lambda_{itj} \dot{x}_{itj}$, technical efficiency change $TE\Delta_{it}$ and allocative inefficiency $\sum_{j=1}^{2} \left(\lambda_{itj} - s_{itj}\right)\dot{x}_{itj}$. As pointed out by *Kumbhakar and Lovell (2000)*, if price information is not available, the allocative inefficiency term cannot be computed. In this case, total factor productivity growth simplifies to:

$$TFPG_{it} = T\Delta_{it} + \left(RTS_{it} - 1\right)\sum_{j=1}^{2} \lambda_{itj} \dot{x}_{itj} + TE\Delta_{it} \qquad (14)$$

The measurement of total factor productivity growth we use in this study is based on equation (14) since we do not have price information on capital and labor for all countries of our sample. *Pires and Garcia (2004)* undertake the same decomposition of productivity growth as above. But they had price information of factors only for 36 countries out of 75 and for a time period spanning from 1970-2000. This shows that if we take account the allocative inefficiency in our study, our sample would be very small both in the number of countries and in the time period. In order to obtain the different values of the productivity components derived in equation (14), we estimate the following flexible translog production function:

$$\begin{aligned} \ln y_{it} = \beta_0 + \beta_t t + \frac{1}{2}\beta_{tt} t^2 + \beta_K \ln K_{it} + \beta_L \ln L_{it} + \frac{1}{2}\beta_{KK}\left(\ln K_{it}\right)^2 + \frac{1}{2}\beta_{LL}\left(\ln L_{it}\right)^2 \\ + \beta_{KL} \ln K_{it} \ln L_{it} + \beta_{tK} t \ln K_{it} + \beta_{tL} t \ln L_{it} - u_{it} + v_{it} \end{aligned} \qquad (15)$$

Where all variables are as defined previously. Technical inefficiency is calculated according to the *Battese and Coelli (1992)* specification:

$$u_{it} = \exp\left\{-\eta\left(t - T_i\right)\right\}u_i \qquad (16)$$

Where $T_i$ is the last period in the *ith* panel; $\eta$ is the decay parameter; $u_i \overset{iid}{\sim} N^+\left(\mu, \sigma_u^2\right)$; $v_{it} \overset{iid}{\sim} N\left(0, \sigma_v^2\right)$; in the model, $u_i$ and $v_{it}$ are distributed independently of each other and the covariates. The parameters $\beta$, $\mu$, $\eta$, $\sigma_v^2$, $\sigma_u^2$, $\sigma_S^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \frac{\sigma_u^2}{\sigma_S^2}$ are estimated by maximum likelihood. Since $\gamma$ must between 0 and 1, the optimization is done in terms of the inverse logit of $\gamma$. Then the components of total factor productivity growth can be calculated as follows:

- The technical change

$$\hat{T}\Delta_{it} = \hat{\beta}_t + \hat{\beta}_{tt}t + \hat{\beta}_{tK}\ln K_{it} + \hat{\beta}_{tL}\ln L_{it} \qquad (17)$$

- The scale component

  The output elasticity of capital, with some abuse of notation, is

$$\hat{\alpha}_{itK} = \hat{\beta}_K + \hat{\beta}_{KK}\ln K_{it} + \hat{\beta}_{KL}\ln L_{it} + \hat{\beta}_{tK}t \qquad (18)$$

  The output elasticity of labor, with some abuse of notation, is

$$\hat{\alpha}_{itL} = \hat{\beta}_L + \hat{\beta}_{LL}\ln L_{it} + \hat{\beta}_{KL}\ln K_{it} + \hat{\beta}_{tL}t \qquad (19)$$

  Then the return to scale is the sum of $\hat{\alpha}_{itK}$ and $\hat{\alpha}_{itL}$. Also we can get $\lambda_{itj}$ and finally calculate the scale component of productivity from these values.

- The technical efficiency change

$$T\hat{E}\Delta_{it} = \hat{\eta}\exp\left\{-\hat{\eta}\left(t - T_i\right)\right\}\hat{u}_i = \hat{\eta}\hat{u}_{it} \qquad (20)$$

With these obtained values we can compute total factor productivity growth as in equation (14).

Now let's explain how each variable in equation (15) is calculated. The variable $y_{it}$ is real GDP corrected for purchasing power parity (PPP) in constant 2000 international $, from the World Development Indicators 2006. The capital stock is computed by the perpetual-inventory method according to the following formula[2]:

$$K_{it+1} = I_{it} + (1-\delta)K_{it} \qquad (21)$$

Where $K_{it}$ is capital stock; $I_{it}$ is investment and $\delta = 0.05$ is the depreciation rate. Investment is measured as gross capital formation in constant 2000 US$ from the World Development Indicators 2006. Labour $L_{it}$ is measured as population per equivalent adult according to the following formula:

$$L_{it} = Population(0-14)*0.5 + \{Population(15-64) + Population(\geq 65)\}*1 \qquad (22)$$

Where $Population(0-14)$ is population between 0 and 14 years; $Population(15-64)$ population between 15 and 64 years and $Population(\geq 65)$ is population from 65 years and above. The data for these variables are from the World Development Indicators 2006. We could obtain labour from the Penn World Tables using the variable Real GDP per worker (*rgdpwok*). We did not proceed like this for two reasons: first, there are lots of missing values in this variable for our sample and second, a thorough analysis of this variable suggests that population per equivalent adult is more reliable, especially for developing countries where there are many children work and large informal sector. Population per equivalent adult was also used by *Pires*

---

[2] For the interested reader, I introduce a new Stata user-writing command named **STOCKCAPIT** that computes capital stock according to this formula. The command is downloadable at: http://ideas.repec.org/c/boc/bocode/s457270.html

*and Garcia (2004)* in their study but they obtained it from a transformation from the Penn World Tables instead of the World Development Indicators.

Table 4 presents the maximum likelihood estimates of the translog stochastic production function given in equation (15). The majority of the coefficients $\beta$ are significant at conventional levels. The Wald test shows that the Cobb Douglas function is rejected as the suitable representation of the data. We conducted a Wald test instead of a likelihood ratio test for the Cobb Douglas specification because we could not obtain the estimates for this restriction in order to perform the likelihood ratio test. The coefficient of the interaction between capital and labor is negative indicating the existence of substitution effect between the two production factors. The coefficient of squared time is positive indicating that the second part of the neutral part of technological progress has a positive effect on output. The signs of the interaction of capital and time, on the one hand, and labor and time, on the other hand, illustrate that the non-neutral part of technological progress increases with capital and decreases with labor. The coefficient of capital is not significant but that of capital squared is positive and significant, meaning that very high levels of capital have a positive effect on output. The coefficient of labor and labor squared are respectively negative and positive. This suggests that at low levels, labor reduces output but very high levels of labor augment output. The inverse logit of $\gamma$ is highly statistically significant and the value of $\gamma$ is very close to 1. This means that a great part of the disturbance term is due to the existence of technical inefficiency. The estimated value of $\eta$ is positive and significant, suggesting that the degree of inefficiency decreases over time toward the base level. The last period for each country $i$ contains the base level of technical inefficiency. The estimated parameters in Table 4 allow us to carry out the decomposition of total factor productivity growth according to equation (14).

### 2.2.2. The measurement of real effective exchange rate volatility

We compute two measurements of real effective exchange rate volatility. The first measurement is calculated according to *Combes et al. (1999)*. We start by estimating the following equation for each country $i$:

$$\ln REER_t = a + bt + c \ln REER_{t-1} + \varepsilon_t \qquad (23)$$

Where $\ln REER$ and $\ln REER_{t-1}$ are respectively the logarithm of real effective exchange rate at time $t$ and time $t-1$; $t$ is the time trend and $\varepsilon_t$ is the error term. We compute the predicted value $\ln RE\hat{E}R_t$ from equation (23), take the exponential of this value and derive the real effective exchange rate volatility as the square root of the variance of the regression model's disturbances for each country and period[3]. The disturbances are measured as the difference between $REER_t$ and $RE\hat{E}R_t$. In the results this first measurement of real effective exchange rate volatility is referred to as REER volatility 1. Note that this variable enters in logarithmic form in the regressions.

The second measurement of real exchange rate instability is calculated as the Fano factor named after the physicist *Ugo Fano* who invented it. It is defined as:

$$F = \frac{\sigma_W^2}{\mu_W} \qquad (24)$$

Where $\sigma_W^2$ is the variance and $\mu_W$ is the mean of a random process in some time window $W$. The time window for our study is defined by the six non overlapping periods. We compute this Fano factor for the real effective exchange rate variable for each country at each period. It is important to note that the Fano factor is similar to variance-to-mean ratio or index of dispersion

[3] Recall that we have six non overlapping periods: 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, and 2000-2004.

when the time window is large or is going to infinity. The index of dispersion like the coefficient of variation is a normalized measure of the dispersion of a probability distribution. In the results this second measurement of real effective exchange rate volatility is referred to as REER volatility 2. Note that this variable enters in logarithmic form in the estimations.

## 3. Results

In this section, we will respectively present the results of the panel data instrumental variable estimation and those of the threshold effect estimation.

### 3.1. Panel data instrumental variable estimation results

All eight equations in Table 5 show that real effective exchange rate volatility is statistically significant at conventional levels and have the expected sign. Except equation (1) and (4), we observe that the effect of REER volatility is not too high. Referring to regression (7), an increase in REER volatility by 100% reduces total factor productivity growth just by an amount equivalent to 0.362 percentage points. These results of the existence of a negative effect between REER volatility and productivity growth corroborate those found by *Aghion et al. 2006*. The absolute value of the REER volatility coefficient in equations (1) and (4) diminishes drastically when we control for both human capital and financial development in regressions (2) and (3), and from estimations (5) to (8). This suggests that the effect of REER volatility on total factor productivity growth may pass through these last two variables. We observe that the standard errors of the coefficients of REER volatility are very small. This implies that the corresponding confidence intervals, though not reported, are tinier meaning that the coefficients of REER volatility are estimated with great precision. The use of instrumental variables in the estimations makes it possible to say that the negative relation between REER volatility and total factor productivity growth seems to go from REER volatility towards productivity growth and not the reverse. The F-test for the joint significance of all the coefficients is fairly high and significant in all equations. The overall R-squared is very low in equations (1) and (4) but becomes large when we introduce human capital and financial development. The number of observations largely decreases when we introduce the crises variable but remains in reasonable proportions in the other estimations. Besides the fact that we lose observations when we introduce the crises variable, we note that there are many observations lost in all equations. This is due to the fact that we have many missing observations in the total factor productivity growth variable. In fact, this variable has a missing value at the beginning period for each country. This is because the calculation of this variable includes the scale effect whose calculation in turn comprises the growth rate of each factor. The measurement of the growth rate of each factor makes that the value at the beginning period for each country is lost.

The results also highlight that total factor productivity growth is strongly positively influenced by human capital and financial development. But the effect of human capital is more marked than that of financial development. The other variables have the expected signs but are statistically insignificant.

The results in Table 6 illustrates that REER volatility affects negatively total factor productivity growth in developed countries. As in the main estimations, we observe that the effect of REER volatility is very small. Also the standard errors of REER volatility are small. But, contrarily to the main results, the coefficient of REER volatility remains stable after we introduce financial development, human capital and, more generally, the other control variables. As in the main estimations, the impact of human capital remains larger than that of financial development. It is important to notice here that inflation and the crises variable become significant in most equations and have the expected signs. The other remaining variables have the expected signs but are not significant. The coefficient of determination is very low in equations (1), (2) and (7) but augments tremendously when we control for inflation and human capital. The F-test is statistically significant in all equations.

Table 7 presents the results of the estimations for the developing countries. As in the previous regressions, REER volatility influences negatively total factor productivity growth. But conversely to the previous results, the effect of REER volatility is very high. Referring to regression (1), an increase in REER volatility by 100% reduces total factor productivity growth by an amount equivalent to 2.41 percentage points. This is approximately 7 times the effect of REER volatility we calculated for the overall sample. This suggests that REER volatility is more harmful to developing countries than to developed countries. Just as in the developed countries, the coefficient of REER volatility is stable and its standard error is small. Openness continues to influence positively total factor productivity growth. The F-test is statistically significant but the coefficient of determination is very low.

In Table 8, we present the estimation results using the second measurement of REER volatility. We see that REER volatility continues to affects negatively total factor productivity growth. As in the main results, the effect of REER volatility is not very high. The standard error of the coefficient of REER volatility is also very low, suggesting a high degree of precision in the estimation of this coefficient. Contrarily to the main estimations, the coefficient of REER volatility remains stable when we introduce financial development and human capital, signifying that the effect of REER volatility on total factor productivity growth may not pass through these variables when we use this second measurement of REER volatility. Like in the main regressions, the impact of human capital and openness are greater than that of financial development. The other control variables have the expected signs but are not significant. The F-test is significant in all equations. The R-squared is very low but increases hugely when we introduce human capital.

### 3.2. <u>Threshold effect estimation results</u>

Table 9 gives the results of the regressions using the threshold effect estimation method *(Hansen (1999))*. Before examining the results, it is important to note that the *Hansen (1999)* method is designed for balanced panel data. Hence, we had to eliminate the missing values from our sample of study. Consequently, we had only 54 countries with a total of 270 observations left out of 74 countries and from periods 1980-1984 to 2000-2004. This drastically reduces the number of observations, but we have a sufficient number of observations on which we can conduct statistical inference. Also for these estimations we use the second measurement of REER volatility. The upper part of Table 9 provides the test for the existence of threshold effects in the estimated equations while the lower part gives the coefficient estimates. The results illustrate that there does not exist a first or a second threshold but there is a third threshold in all equations. This, because the bootstrapped p-value shows that the triple threshold is statistically significant at 10% level. Moreover referring to regression 4 in Table 9, Figure 1 depicts that the $LR_3(\gamma)$ curve touches the x-axis between (-1.5) and (-1.0). Hence there exists a triple threshold value $\hat{\gamma}$ between these two values. The estimate of this threshold is very precise since the confidence interval for this parameter is very narrow. Recall that the confidence interval for the threshold parameter corresponds to the values of $LR_3(\gamma)$ that are below the dashed horizontal line. The coefficient of REER volatility below the second threshold is highly statistically significant but since the corresponding threshold is not significant, we conclude that REER volatility has no impact on total factor productivity growth at this threshold level. Thus for very low levels of financial development, REER volatility has no effect on total factor productivity growth. On the other hand, the coefficient of REER volatility below the third threshold is negative, highly significant and its corresponding threshold is also statistically significant. Consequently, for moderately financially developed countries, REER volatility reacts negatively on productivity. Although this negative effect is not economically very high, it remains robust to the introduction of control variables. It is also very precise since its standard errors are very small. The coefficient of REER volatility above the third threshold is positive but is not statistically significant. Hence for highly financially developed countries, REER volatility has no impact on productivity. Referring to equation (4), we see that the estimated triple threshold is equal to (-1.216962) and keeps the same value across all equations. The corresponding level of financial development is 0.2961. This value is slightly below the median of financial development. This illustrates that there are a lot of countries above this threshold level and that it is not out of sample. As in the main estimations in Table 5, openness has a larger effect than financial development. But contrarily to the main results, government consumption and inflation are significant and have the expected signs.

## Conclusion

For a long time, economists were not interested in the relation between business cycle and economic growth but since *Ramey and Ramey (1995)*, the number of works studying this link has exploded. In line with these studies, the connection between real exchange rate volatility and productivity growth has also recently been examined. The theory suggests that real exchange rate volatility acts on productivity according to some threshold variable: financial development or liability dollarization. We studied the effects of REER volatility on total factor productivity growth using a panel data of 74 countries from 1975 to 2004. Using panel data instrumental variables and threshold effects estimation methods, we first found that REER volatility affects negativity total factor productivity growth and second, we discovered that this impact of REER volatility depends on the level of financial development of the countries.

Although the results were lighting, some warnings deserve to be underlined. Firstly, we did not include liability dollarization or an equivalent measurement beside financial development as a threshold variable. Secondly, although the threshold effect estimation method takes into account the unobservable heterogeneity of the countries, it does not control for the endogeneity of REER volatility[4]. Thirdly, we did not isolate, empirically, the precise channels through which REER volatility affects total factor productivity growth nor have we studied the impact of REER volatility on the components of productivity growth.

From policy perspectives, the results found in this paper indicate that the negative effects of REER volatility in the long term are not negligible. Hence efforts made in reducing REER volatility will be translated, in the long-run, by huge productivity gains.

[4] There does not exist, to this date, a method of estimation of threshold effects with instrumental variables on panel data.

## References

**Aghion, P. and G. Saint Paul: 1998**, Uncovering Some Causal Relationships between Productivity Growth and the Structure of Economic Fluctuations: A Tentative Survey, *Labor 12*, 279–303.

**Aghion, P., P. Bacchetta, R. Ranciere and K. Rogoff: 2006**, Exchange Rate Volatility and Productivity Growth: The Role of Financial Development, *National Centre of Competence in Research Financial Valuation and Risk Management, Working Paper* number 288.

**Aizenman, J. and N. Marion: 1993**, Policy Uncertainty, Persistence, and Growth, *Review of International Economics* 1 (2), 145–63.

**Battese, G. E. and T. J. Coelli: 1992**, Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India, *Journal of Productivity Analysis* 3, 153-169.

**Benhima, K.: 2010**, Exchange Rate Volatility and Productivity Growth: the Role of Liability Dollarization, *mimeo, University of Lausanne*.

**Bernanke, B. S.: 1983**, Irreversibility, Uncertainty and Cyclical Investment, *Quarterly Journal of Economics* 98(1), 85–106.

**Caporale, G. M., T. H. Amor and C. Rault: 2009**, Sources of Real Exchange Rate Volatility and International Financial Integration: A Dynamic GMM Panel Data Approach, *Brunel University West London, Working Paper* number 09-21.

**Combes, J. L., P. Guillaumont, S. Guillaumont, Jeanneney and P. Motel, Combes: 1999**, Ouverture sur l'extérieur et instabilité des taux de croissance, *Etudes et Documents, CERDI, CNRS, Université d'Auvergne*.

**Drautzburg, T.: 2007**, Growth Effects of Real Exchange Rate Volatility, *mimeo, Kiel Institute for the World Economy, Advanced Studies Program*.

**Friedman, M.: 1953**, Essays in Positive Economics, *Chicago Press*.

**Grier, K. and A. D. Smallwood: 2007**, Uncertainty and export performance: Evidence from 18 countries, *Journal of Money, Credit and Banking* 39, 965-979.

**Grier, K. B. and G. Tullock: 1989**, An Empirical Analysis of Cross-National Economic Growth, 1951–80, *Journal of Monetary Economics* 24 (2), 259–76.

**Guillaumont, P.: 1999**, On the Economic Vulnerability of Low Income Countries, *mimeo, CERDI-CNRS, Université d'Auvergne, France*.

**Hansen, B.: 1999**, Threshold Effects in Non-Dynamic Panels: Estimation, Testing, and Inference, *Journal of Econometrics* 93 (2), 345–68.

**Hnatkovska, V. and N. Loayza: 2003**, Volatility and Growth, *World Bank*, *Policy Research Working Paper Series* number 3184.

**Imbs, J.: 2006**, Growth and Volatility, *Swiss Finance Institute*, *Research Paper Series* number 06–9.

**Keynes, J. M.: 1936**, The General Theory of Employment, Interest, and Money, *London: Macmillan.*

**Klein, M. W., S. Schuh and R. Triest: 2003**, Job creation, job destruction and the real exchange rate, *Journal of International Economics* 59 (2), 239-265.

**Kormendi, R. and P. Meguire: 1985**, Macroeconomic Determinants of Growth, *Journal of Monetary Economics* 16 (2), 141–63.

**Kumbhakar, S. C. and C. A. K. Lovell: 2000**, Stochastic Frontier Analysis, *Cambridge University Press, Cambridge*.

**Norrbin, S. C. and F. P. Yigit: 2005**, The Robustness of the Link between Volatility and Growth of Output, *Review of World Economics* 141 (2), 343-356.

**Pires, J. O. and F. Garcia: 2004**, Productivity of Nations: A Stochastic Frontier Approach to TFP Decomposition, *Escola de Economia de Sao Paulo, Testos para Discussao* 143.

**Rafferty, M.: 2005**, The Effects of Expected and Unexpected Volatility on Long-Run Growth: Evidence from 18 Developed Economies, *Southern Economic Journal* 71 (3), 582-591.

**Ramey, G. and V. Ramey: 1995**, Cross-Country Evidence on the Link between Volatility and Growth, *American Economic Review* 85 (5), 1138–50.

**Schnabl, G.: 2007**, Exchange Rate Volatility and Growth in Small Open Economies at the EMU Periphery, *European Central Bank, Working Paper Series* number 773.

**Schumpeter, J. A.: 1939**, Business Cycle: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process, *New York: McGraw-Hill*.

**Table 1: Definitions and methods of calculation of the control variables**

| Variables | Definitions | Expected Sign | Sources of data |
|---|---|---|---|
| Financial development | log of domestic credit to private sector over GDP | Positive | World Development Indicators, 2006 |
| Openness | log of exports + imports to GDP | Positive | |
| Human capital | log of the average number of years of studies in the secondary. The initial value of this variable was taken for each period. | Positive | Barro and Lee (2010) |
| Government consumption | log of government consumption over GDP | Negative | World Development Indicators, 2006 |
| Inflation | log of one plus inflation rate | Negative | World Development Indicators, 2006, and International Financial Statistics (IFS), April 2006 |
| Tendency of terms of trade | growth rate of terms of trade | Positive | World Development Indicators, 2006 |
| Crises | = 1 if banking or financial crises<br>= 0 otherwise | Negative | Caprio and Klingebiel (2003), and Kaminski and Reinhart (1999) |

For the definitions and source of the total factor productivity growth and the real effective exchange rate volatility variables, see the text.

**Table 2: Summary statistics for all the variables**

| Variables | Obs. | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Total factor productivity growth | 362 | 0.0276 | 0.0414 | -0.1017 | 0.1883 |
| REER volatility 1[+] | 386 | 1.5074 | 2.6431 | -12.1301 | 8.0975 |
| REER volatility 2[+] | 389 | 0.3282 | 2.7418 | -8.0648 | 8.7680 |
| Financial development[+] | 437 | -1.0920 | 0.8415 | -3.9535 | 3.4597 |
| Openness[+] | 438 | -0.5024 | 0.5765 | -2.1324 | 1.1490 |
| Human capital[+] | 426 | 0.3724 | 0.8158 | -2.8189 | 1.7444 |
| Government consumption[+] | 443 | -1.9603 | 0.4028 | -3.2156 | -0.6093 |
| Inflation[+] | 444 | 0.1623 | 0.3944 | -0.0231 | 3.5432 |
| Tendency of terms of trade | 438 | 0.0028 | 0.0431 | -0.1376 | 0.2620 |
| Crises | 360 | 0.2118 | 0.3195 | 0 | 1 |

[+] These variables are measured in logarithms

## Table 3: List of the 74 countries in the studied sample

| Developed countries | | |
|---|---|---|
| No. | World Bank Code | Countries |
| 1 | AUS | Australia |
| 2 | AUT | Austria |
| 3 | BEL | Belgium |
| 4 | CAN | Canada |
| 5 | CHE | Switzerland |
| 6 | DEU | Germany |
| 7 | DNK | Denmark |
| 8 | ESP | Spain |
| 9 | FIN | Finland |
| 10 | GBR | United Kingdom |
| 11 | GRC | Greece |
| 12 | HKG | Hong Kong, China |
| 13 | IRL | Ireland |
| 14 | ISL | Iceland |
| 15 | ITA | Italy |
| 16 | JPN | Japan |
| 17 | KOR | Korea, Rep. |
| 18 | LUX | Luxembourg |
| 19 | NLD | Netherlands |
| 20 | NOR | Norway |
| 21 | NZL | New Zealand |
| 22 | PRT | Portugal |
| 23 | SGP | Singapore |
| 24 | SWE | Sweden |

| Developing Countries | | | | | |
|---|---|---|---|---|---|
| No. | World Bank Code | Countries | No. | World Bank Code | Countries |
| 1 | ARG | Argentina | 25 | HND | Honduras |
| 2 | BDI | Burundi | 26 | HTI | Haiti |
| 3 | BEN | Benin | 27 | HUN | Hungary |
| 4 | BFA | Burkina Faso | 28 | IDN | Indonesia |
| 5 | BGD | Bangladesh | 29 | IND | India |
| 6 | BOL | Bolivia | 30 | IRN | Iran, Islamic Rep. |
| 7 | BRA | Brazil | 31 | JOR | Jordan |
| 8 | BWA | Botswana | 32 | KEN | Kenya |
| 9 | CHL | Chile | 33 | LKA | Sri Lanka |
| 10 | CHN | China | 34 | LSO | Lesotho |
| 11 | CIV | Cote d'Ivoire | 35 | MAR | Morocco |
| 12 | CMR | Cameroon | 36 | MEX | Mexico |
| 13 | COG | Congo, Rep. | 37 | MLI | Mali |
| 14 | COL | Colombia | 38 | MRT | Mauritania |
| 15 | CRI | Costa Rica | 39 | MWI | Malawi |
| 16 | DOM | Dominican Republic | 40 | MYS | Malaysia |
| 17 | DZA | Algeria | 41 | NIC | Nicaragua |
| 18 | ECU | Ecuador | 42 | PAK | Pakistan |
| 19 | GAB | Gabon | 43 | PER | Peru |
| 20 | GHA | Ghana | 44 | PHL | Philippines |
| 21 | GMB | Gambia, The | 45 | PRY | Paraguay |
| 22 | GNB | Guinea-Bissau | 46 | SEN | Senegal |
| 23 | GTM | Guatemala | 47 | SLV | El Salvador |
| 24 | GUY | Guyana | 48 | SWZ | Swaziland |
| | | | 49 | TGO | Togo |
| | | | 50 | THA | Thailand |

**<u>Table 4:</u> Estimation of the translog stochastic production function**

| Dependent variable: $\ln y$ | | |
|---|---|---|
| Regressors | Coefficients | Std. Err. |
| $t$ | -0.0121 | 0.0723 |
| $(1/2)t^2$ | 0.0069* | 0.0041 |
| $\ln K$ | 0.2323 | 0.1754 |
| $\ln L$ | -0.7615*** | 0.2695 |
| $(1/2)(\ln K)^2$ | 0.0327*** | 0.0098 |
| $(1/2)(\ln L)^2$ | 0.1240*** | 0.0255 |
| $\ln K \ln L$ | -0.0304* | 0.0160 |
| $t \ln K$ | 0.0102*** | 0.0028 |
| $t \ln L$ | -0.0173*** | 0.0046 |
| Constant | 17.5921*** | 2.9582 |
| $\mu$ | 0.0682 | 0.2992 |
| $\eta$ | 0.0852*** | 0.0097 |
| $\ln \sigma_S^2$ | -1.4390*** | 0.5071 |
| Inverse logit of $\gamma$ | 3.0663*** | 0.5359 |
| $\sigma_S^2$ | 0.2372 | 0.1203 |
| $\gamma$ | 0.9555 | 0.0228 |
| $\sigma_u^2$ | 0.2266 | 0.1203 |
| $\sigma_v^2$ | 0.0106 | 0.0008 |

*** p<0.01, ** p<0.05, * p<0.1

**Table 5: Panel data instrumental variable estimation results for all countries with the variable REER volatility 1**

| Dependent Variable: Total factor productivity growth | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Regressors | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| REER volatility 1$^{+}$ | -0.0143*** | -0.00407** | -0.00413** | -0.0141** | -0.00343** | -0.00412** | -0.00362* | -0.00339* |
| | (0.00550) | (0.00205) | (0.00202) | (0.00545) | (0.00172) | (0.00202) | (0.00187) | (0.00172) |
| Openness$^{+}$ | 0.0166* | | | 0.0169* | | | | |
| | (0.00869) | | | (0.00867) | | | | |
| Human capital$^{+}$ | | 0.0399*** | 0.0387*** | | 0.0382*** | 0.0386*** | 0.0377*** | 0.0381*** |
| | | (0.00299) | (0.00296) | | (0.00310) | (0.00298) | (0.00318) | (0.00310) |
| Financial development$^{+}$ | | | 0.00511*** | | 0.00522*** | 0.00522*** | 0.00518*** | 0.00535*** |
| | | | (0.00174) | | (0.00171) | (0.00177) | (0.00175) | (0.00174) |
| Inflation$^{+}$ | | | | -0.000573 | | | | |
| | | | | (0.00597) | | | | |
| Government consumption$^{+}$ | | | | -0.00726 | | -0.00148 | | -0.00181 |
| | | | | (0.0101) | | (0.00469) | | (0.00474) |
| Crises | | | | | -0.000423 | | -0.000166 | -0.000476 |
| | | | | | (0.00286) | | (0.00295) | (0.00286) |
| Tendency of terms of trade | | | | | | | 4.51e-05 | |
| | | | | | | | (0.0220) | |
| Constant | 0.0584*** | 0.0147*** | 0.0210*** | 0.0441** | 0.0202*** | 0.0183* | 0.0209*** | 0.0167 |
| | (0.00975) | (0.00429) | (0.00448) | (0.0213) | (0.00437) | (0.00953) | (0.00452) | (0.0102) |
| Observations | 306 | 296 | 294 | 306 | 234 | 294 | 229 | 234 |
| Number of countries | 69 | 67 | 67 | 69 | 54 | 67 | 53 | 54 |
| F test | 6.9760 | 95.16 | 67.50 | 3.754 | 49.29 | 50.46 | 36.55 | 39.49 |
| P-value F | 0.00114 | 0 | 0 | 0.00557 | 0 | 0 | 0 | 0 |
| R-squared overall | 0.00114 | 0.142 | 0.150 | 0.00239 | 0.234 | 0.149 | 0.232 | 0.235 |

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
+ These variables are measured in logarithms

**Table 6: Panel data instrumental variable estimation results for developed countries with the variable REER volatility 1**

| Dependent Variable: Total factor productivity growth | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Regressors | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| REER volatility 1+ | -0.00688** | -0.00630** | -0.00475** | -0.00311* | -0.00327* | -0.00313* | -0.00758** | -0.00332* |
| | (0.00293) | (0.00283) | (0.00199) | (0.00184) | (0.00176) | (0.00185) | (0.00362) | (0.00179) |
| Financial development+ | 0.00828** | 0.00669* | | | | | 0.00803** | |
| | (0.00351) | (0.00348) | | | | | (0.00368) | |
| Crises | | -0.0120* | -0.00863* | | -0.00601 | | | -0.00593 |
| | | (0.00709) | (0.00497) | | (0.00406) | | | (0.00413) |
| Inflation+ | | | -0.173*** | -0.131*** | -0.121*** | -0.132*** | | -0.125*** |
| | | | (0.0271) | (0.0288) | (0.0271) | (0.0310) | | (0.0291) |
| Human capital+ | | | | 0.0305*** | 0.0324*** | 0.0306*** | | 0.0328*** |
| | | | | (0.0101) | (0.0105) | (0.0102) | | (0.0107) |
| Government consumption+ | | | | | | -0.00148 | | -0.00640 |
| | | | | | | (0.0156) | | (0.0166) |
| Tendency of terms of trade | | | | | | | 0.0377 | |
| | | | | | | | (0.0960) | |
| Constant | 0.0566*** | 0.0642*** | 0.0661*** | 0.0170 | 0.0218 | 0.0144 | 0.0584*** | 0.0103 |
| | (0.00688) | (0.00794) | (0.00563) | (0.0150) | (0.0160) | (0.0320) | (0.00819) | (0.0341) |
| Observations | 102 | 72 | 74 | 104 | 74 | 104 | 97 | 74 |
| Number of countries | 24 | 17 | 17 | 24 | 17 | 24 | 23 | 17 |
| F test | 5.8210 | 3.681 | 18.07 | 31.42 | 25.29 | 23.20 | 3.233 | 19.69 |
| P-value F | 0.00445 | 0.0177 | 3.03e-08 | 0 | 0 | 0 | 0.0273 | 5.89e-11 |
| R-squared overall | 0.000941 | 0.00734 | 0.137 | 0.174 | 0.203 | 0.173 | 0.00563 | 0.188 |

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
+ These variables are measured in logarithms

**Table 7: Panel data instrumental variable estimation results for developing countries with the variable REER volatility 1**

| Dependent Variable: Total factor productivity growth | | |
|---|---|---|
| Regressors | (1) | (2) |
| REER volatility 1+ | -0.0241* | -0.0158** |
| | (0.0145) | (0.00699) |
| Openness+ | 0.0243* | 0.0214** |
| | (0.0134) | (0.0106) |
| Government consumption+ | | -0.0048 |
| | | (0.0112) |
| Crises | | 0.0139 |
| | | (0.0105) |
| Constant | 0.0690*** | 0.0415 |
| | (0.0256) | (0.0267) |
| | | |
| Observations | 207 | 172 |
| Number of countries | 46 | 39 |
| F test | 2.483 | 2.329 |
| P-value F | 0.0867 | 0.0595 |
| R-squared overall | 0.0043 | 0.0152 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

+ These variables are measured in logarithms

**<u>Table 8:</u> Panel data instrumental variable estimation results for all countries with the variable REER volatility 2**

| Dependent Variable: Total factor productivity growth | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Regressors | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| REER volatility 2+ | -0.00355* | -0.00857** | -0.00627** | -0.00768** | -0.00744** | -0.00299* | -0.00355* | -0.00626** |
| | (0.00195) | (0.00345) | (0.00300) | (0.00381) | (0.00369) | (0.00170) | (0.00191) | (0.00308) |
| Inflation+ | | -0.00252 | | | -0.000487 | | | |
| | | (0.00533) | | | (0.00478) | | | |
| Government consumption+ | | -0.00549 | | -0.00472 | | | -7.67e-05 | |
| | | (0.00950) | | (0.00845) | | | (0.00505) | |
| Financial development+ | 0.00609*** | 0.00748** | 0.00522* | 0.00589* | 0.00550* | 0.00599*** | 0.00608*** | 0.00523* |
| | (0.00189) | (0.00359) | (0.00302) | (0.00335) | (0.00326) | (0.00183) | (0.00193) | (0.00302) |
| Human capital+ | 0.0372*** | | | | | 0.0366*** | 0.0372*** | |
| | (0.00335) | | | | | (0.00357) | (0.00337) | |
| Openness+ | | | 0.0137* | 0.0169** | 0.0167** | | | 0.0136* |
| | | | (0.00738) | (0.00709) | (0.00691) | | | (0.00737) |
| Crises | | | -0.000302 | | | -0.000748 | | -0.000304 |
| | | | (0.00483) | | | (0.00297) | | (0.00484) |
| Tendency of terms of trade | | | | | | | | 0.00181 |
| | | | | | | | | (0.0378) |
| Constant | 0.0165*** | 0.0258 | 0.0410*** | 0.0329** | 0.0417*** | 0.0168*** | 0.0164 | 0.0410*** |
| | (0.00312) | (0.0185) | (0.00474) | (0.0165) | (0.00459) | (0.00335) | (0.00994) | (0.00474) |
| Observations | 296 | 309 | 240 | 304 | 305 | 236 | 295 | 240 |
| Number of countries | 67 | 70 | 55 | 69 | 69 | 54 | 67 | 55 |
| F test | 58.82 | 2.900 | 4.160 | 4.007 | 4.342 | 44.39 | 43.57 | 3.422 |
| P-value F | 0 | 0.0227 | 0.00301 | 0.00367 | 0.00210 | 0 | 0 | 0.00560 |
| R-squared overall | 0.149 | 0.00441 | 0.00848 | 0.00460 | 0.00636 | 0.224 | 0.149 | 0.00863 |

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
+ These variables are measured in logarithms

# <u>Table 9:</u> Threshold effect estimation method for all countries with the variable REER volatility 2

| Dependent Variable: Total factor productivity growth | | | | |
|---|---|---|---|---|
| Regressors | (1) | (2) | (3) | (4) |
| Estimated single threshold | -2.110279 | -2.110279 | -2.110279 | -2.110279 |
| F1 single threshold | 9.698860 | 10.228568 | 9.388542 | 9.877381 |
| Bootstrap p-value single threshold | [0.163333] | [0.166667] | [0.236667] | [0.196667] |
| Estimated double threshold | -2.180058 | -2.180058 | -2.180058 | -2.180058 |
| F1 double threshold | 9.384393 | 9.278434 | 9.015172 | 8.793222 |
| Bootstrap p-value double threshold | [0.216667] | [0.290000] | [0.246667] | [0.303333] |
| Estimated triple threshold | -1.216962 | -1.216962 | -1.216962 | -1.216962 |
| F1 triple threshold | 9.543235* | 9.435386* | 9.243788* | 9.025115* |
| Bootstrap p-value triple threshold | [0.060000] | [0.090000] | [0.086667] | [0.086667] |
| REER volatility 2 threshold 1+ | 0.000244 | 0.000369 | 0.000285 | 0.000434 |
| | (0.001406) | (0.001358) | (0.001399) | (0.001345) |
| REER volatility 2 threshold 2+ | 0.008188*** | 0.008205*** | 0.008103*** | 0.008089*** |
| | (0.001729) | (0.001699) | (0.001766) | (0.001747) |
| REER volatility 2 threshold 3+ | -0.002226*** | -0.002194*** | -0.002164*** | -0.002106*** |
| | (0.000725) | (0.000728) | (0.000733) | (0.000739) |
| REER volatility 2 threshold 4+ | 0.000174 | 0.000173 | 0.000200 | 0.000208 |
| | (0.000364) | (0.000367) | (0.000366) | (0.000366) |
| Openness+ | 0.013826*** | 0.013617*** | 0.013489*** | 0.013137*** |
| | (0.004273) | (0.004217) | (0.004290) | (0.004221) |
| Financial development+ | 0.006615*** | 0.007448*** | 0.006409*** | 0.007220*** |
| | (0.001915) | (0.002179) | (0.001902) | (0.002154) |
| Government consumption+ | | -0.010631** | | -0.011353** |
| | | (0.005249) | | (0.005263) |
| Inflation | | | -0.002083 | -0.002871* |
| | | | (0.001572) | (0.001711) |
| Observations | 270 | 270 | 270 | 270 |
| Number of countries | 54 | 54 | 54 | 54 |

P-values in square brackets; robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Number of Bootstrap replications 300
+ These variables are measured in logarithms

**Figure 1: Confidence interval for the triple threshold effect (regression 4 in Table 9)**